Transition modelling in the CIRA UZEN flow solver

1st AIAA Transition Modeling and Prediction Workshop

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Outline

- Flow solver description
- Case 0 – Fully Turbulent 3D Bump in Channel
- Case 1 – Zero-Pressure-Gradient Flat Plate
  - Case 1A – Grid resolution on T3A
  - Case 1B – Grid resolution on T3B
- Case 2 – NLF(1)-0416 Airfoil
  - Case 2A – Grid resolution at $\alpha = 0°, 5°$
  - Case 2B – Polar on medium grid
  - Case 2C – Polar on fine grid

RANS Flow solver

UZEN Code

- Flow Solver for steady and unsteady Euler, and RANS equations
- Spatial Discretization
  - Structured Multi-Block, Finite Volume
  - Cell Centered with blended 2nd and 4th order artificial dissipation
- Dual-Time Stepping for unsteady flows
- Time Advancement for steady flows
  - Runge-Kutta with multigrid, local time-stepping, residual averaging
- Turbulence Models
  - Baldwin-Lomax
  - Spalart-Allmaras
  - Myong-Kasagi, NLEV (Shih formulation) κ-ε
  - κ-ω : Wilcox, Kok TNT, Menter BSL and SST, SST-LR
  - DES for SA and κ-ω SST
  - XLES for κ-ω TNT

Transition Model

Transport equation for intermittency

$$\frac{\partial \rho\gamma}{\partial t} + \frac{\partial \rho U_j \gamma}{\partial x_j} = P_\gamma - D_\gamma + \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_\gamma}\right)\frac{\partial \gamma}{\partial x_j}\right]$$

$$P_\gamma = F_{length}\rho S\gamma(1-\gamma)F_{onset}$$

$$D_\gamma = c_{a2}\rho\Omega\gamma F_{turb}(C_{e2}\gamma - 1)$$

Triggering functions (analytical)

SST turbulence model interaction (P_k^{lim} additional production term)

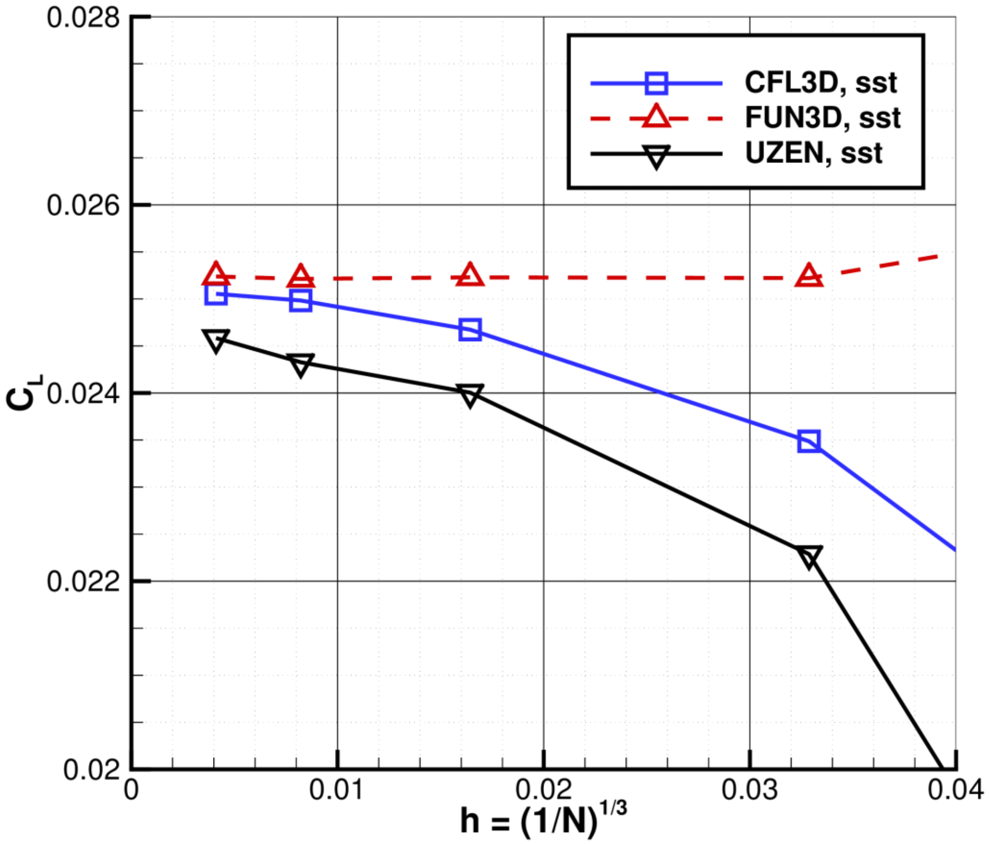
$$\frac{\partial \rho\kappa}{\partial t} + \frac{\partial \rho U_j \kappa}{\partial x_j} = \gamma P_\kappa + P_\kappa^{lim} - \max(\gamma, 0.1)\, D_\kappa + \frac{\partial}{\partial x_j}\left[(\mu + \sigma_\kappa \mu_t)\frac{\partial \kappa}{\partial x_j}\right]$$

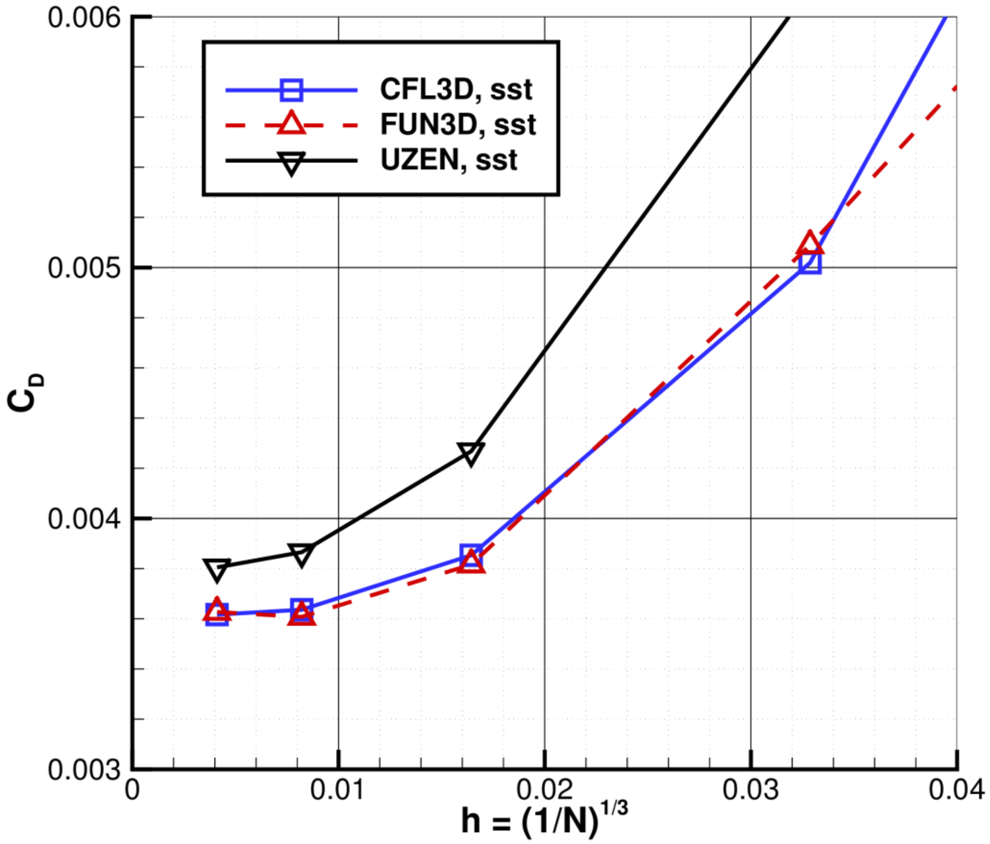
- No sustaining terms
- Limiter on dissipation disabled

Menter, F.R., Smirnov, P.E., Liu, T. *et al.* A One-Equation Local Correlation-Based Transition Model. *Flow Turbulence Combust* **95,** 583–619 (2015). https://doi.org/10.1007/s10494-015-9622-4

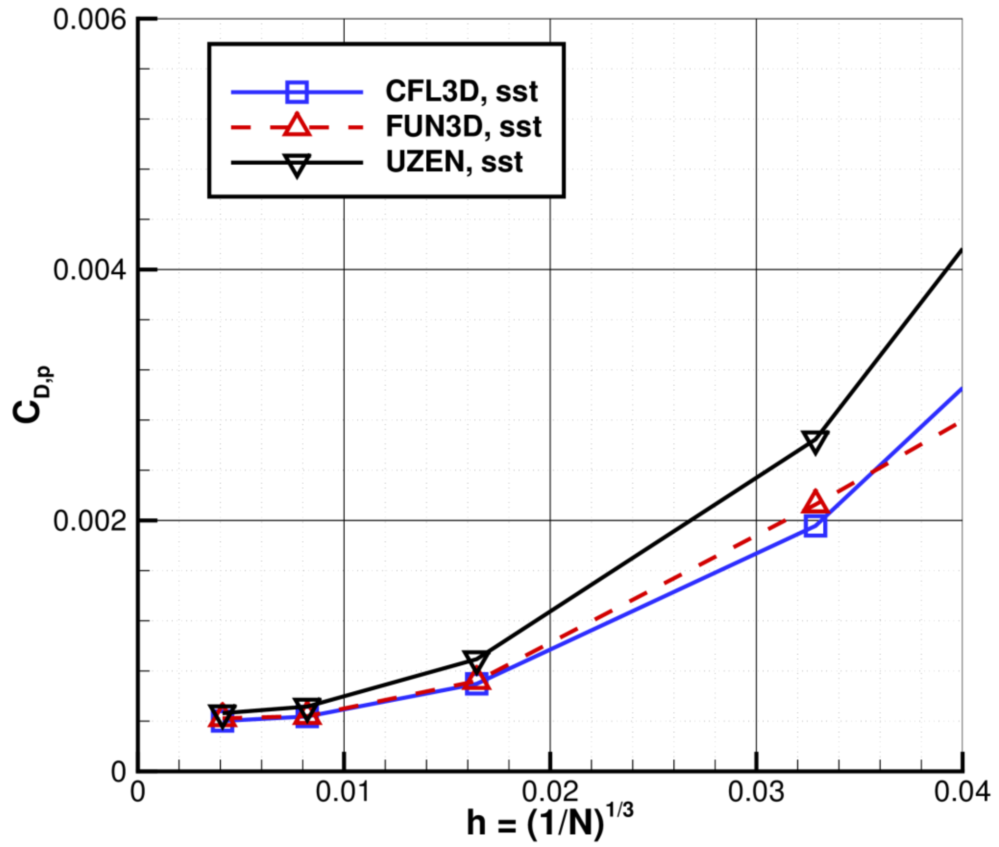
Case 0: Fully Turbulent 3D Bump-in-Channel

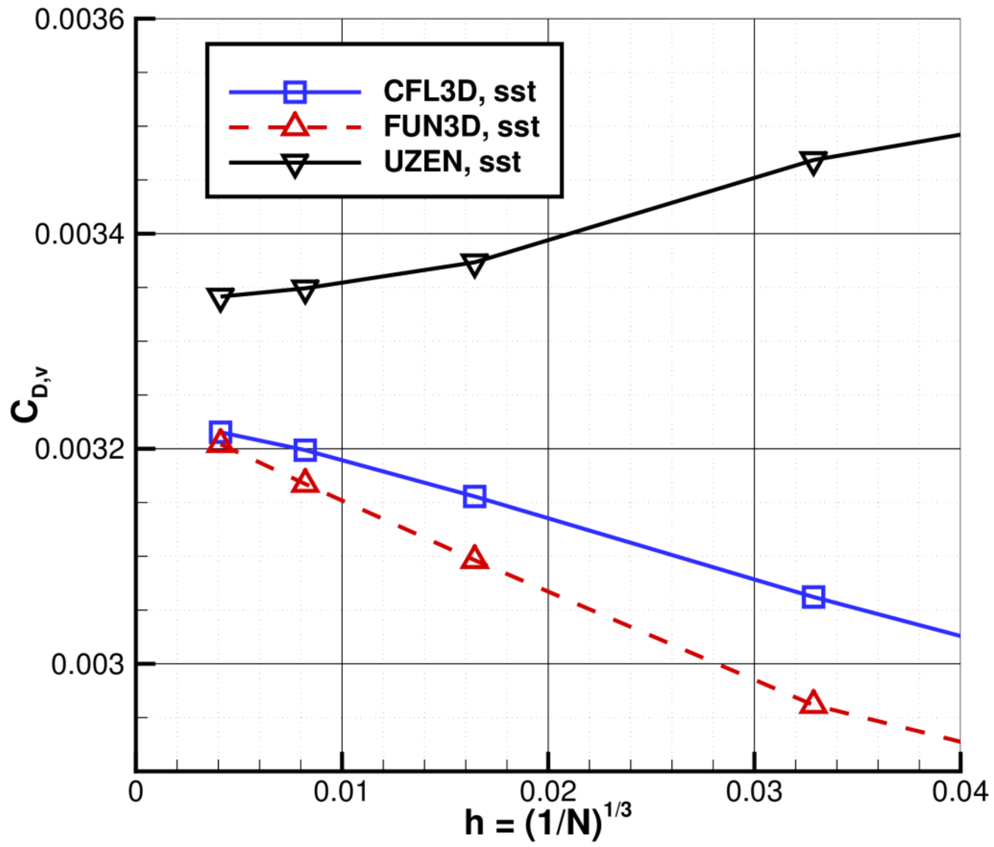
Grids: PLOT3D structured version





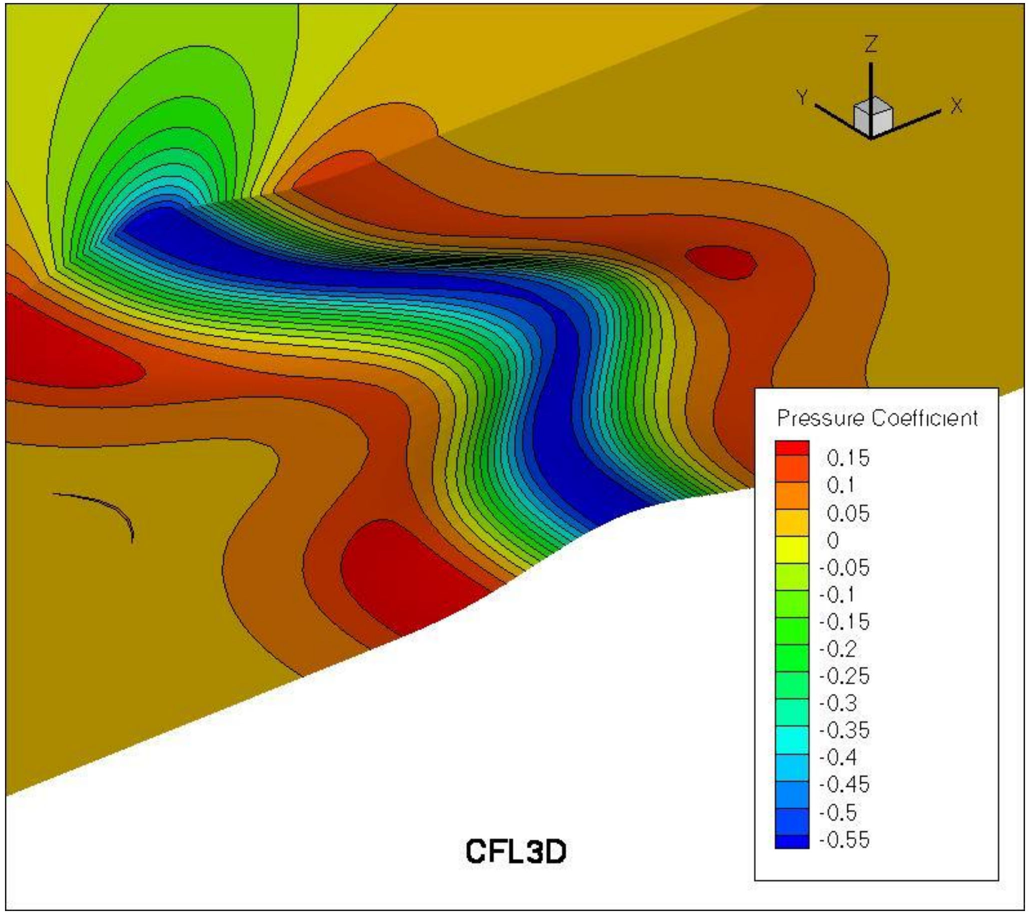
Case 0: Fully Turbulent 3D Bump-in-Channel

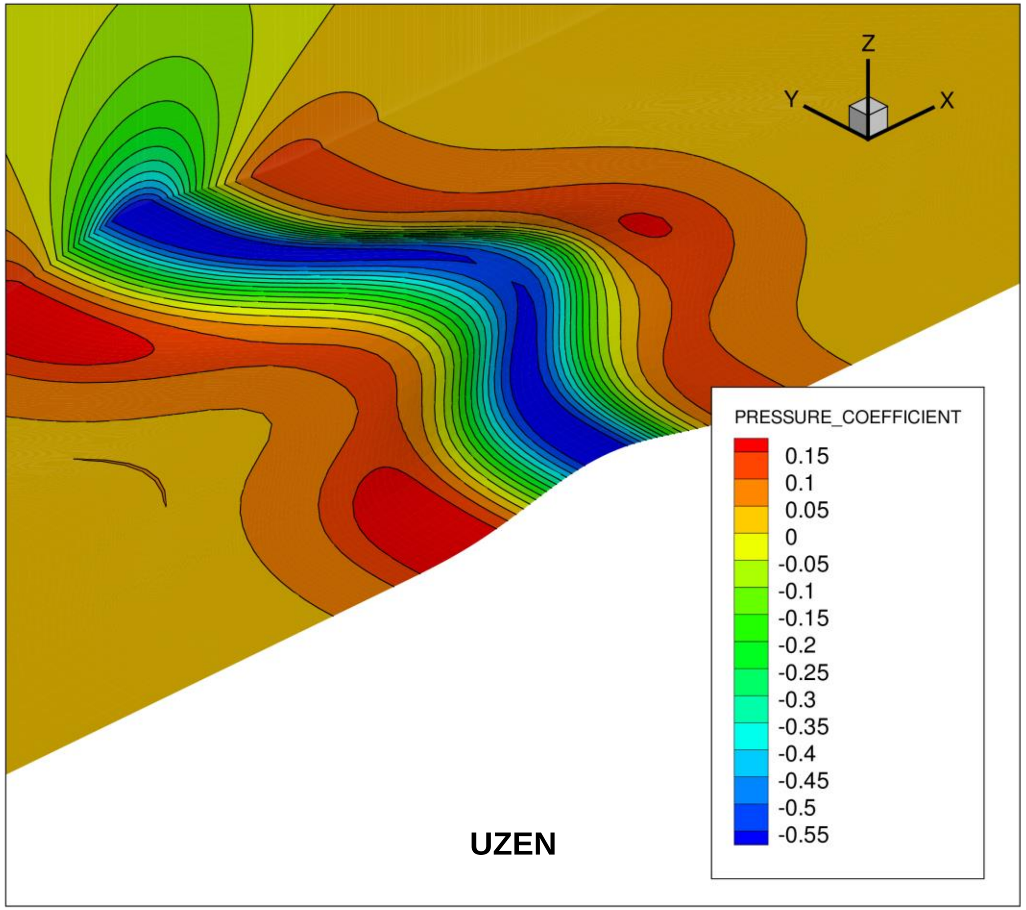




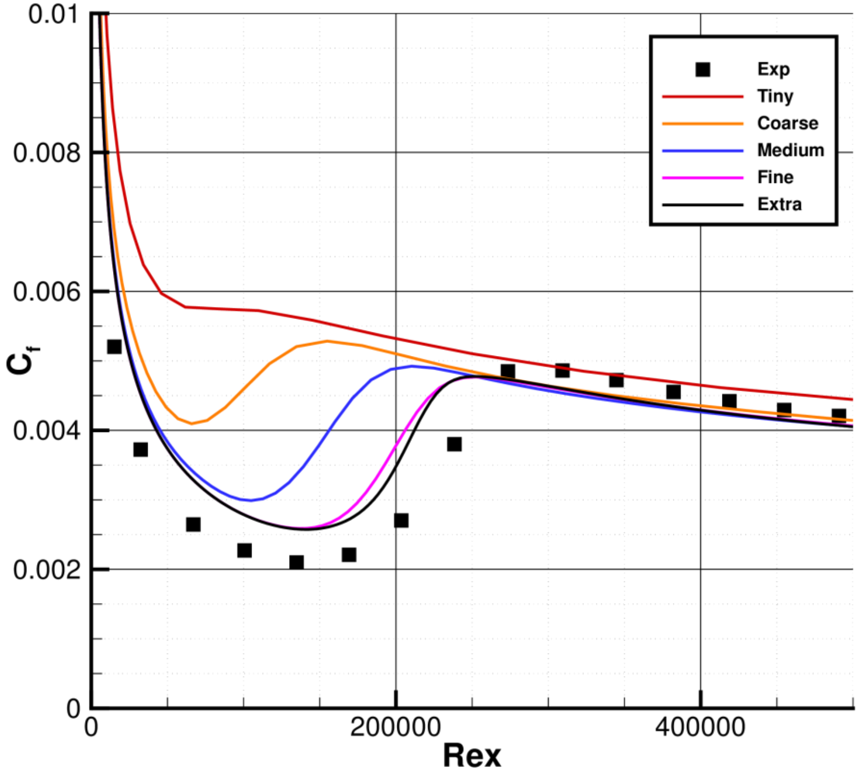
Code	Quantity	Computed apparent order, p	Approx rel fine-grid error, e_a^{21}	Extrap rel fine-grid error, e_{ext}^{21}	Fine-grid convergence index, GCI_{fine}^{21}
CFL3D	C_d	3.49	0.532%	0.052%	0.065%
UZEN		2.3	1.93%	0.283%	0.353%

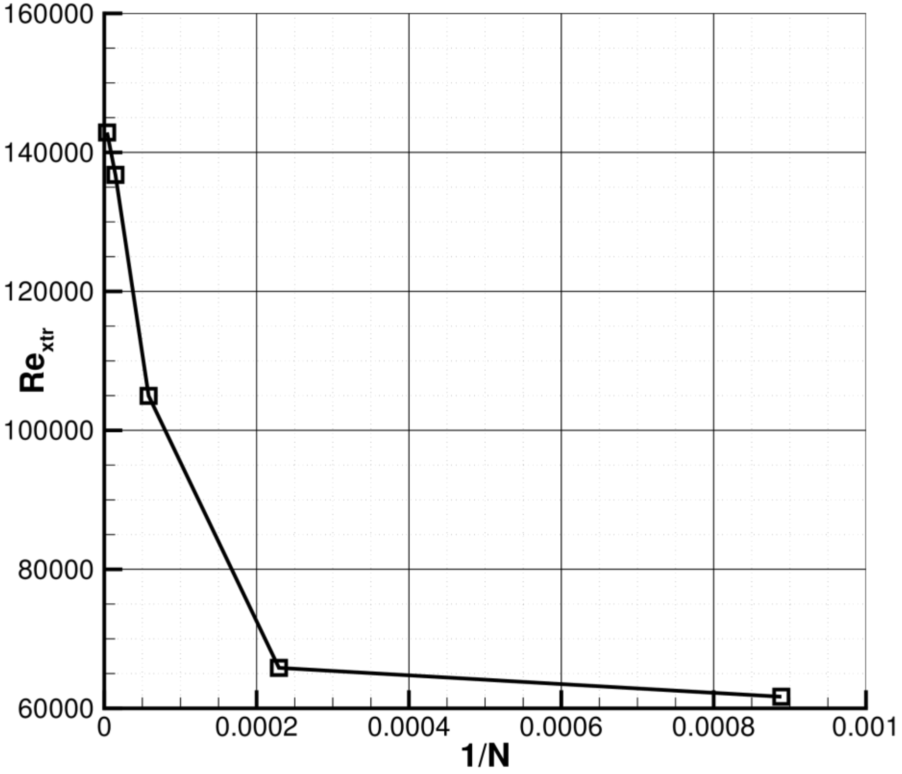
Case 0: Fully Turbulent 3D Bump-in-Channel





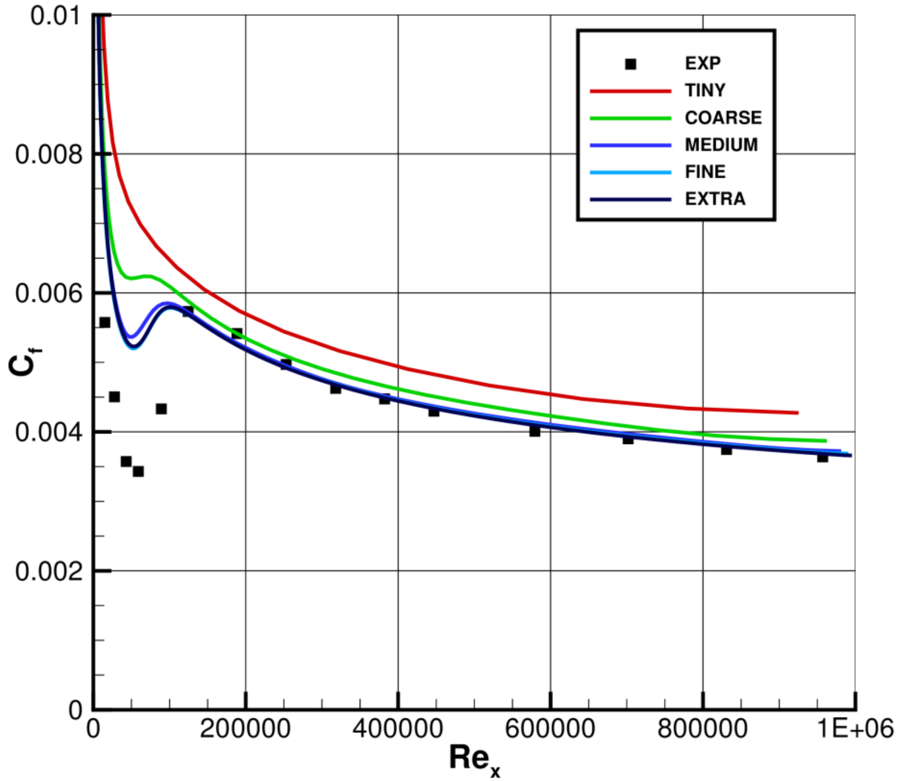
Case 1A: T3A ZPG

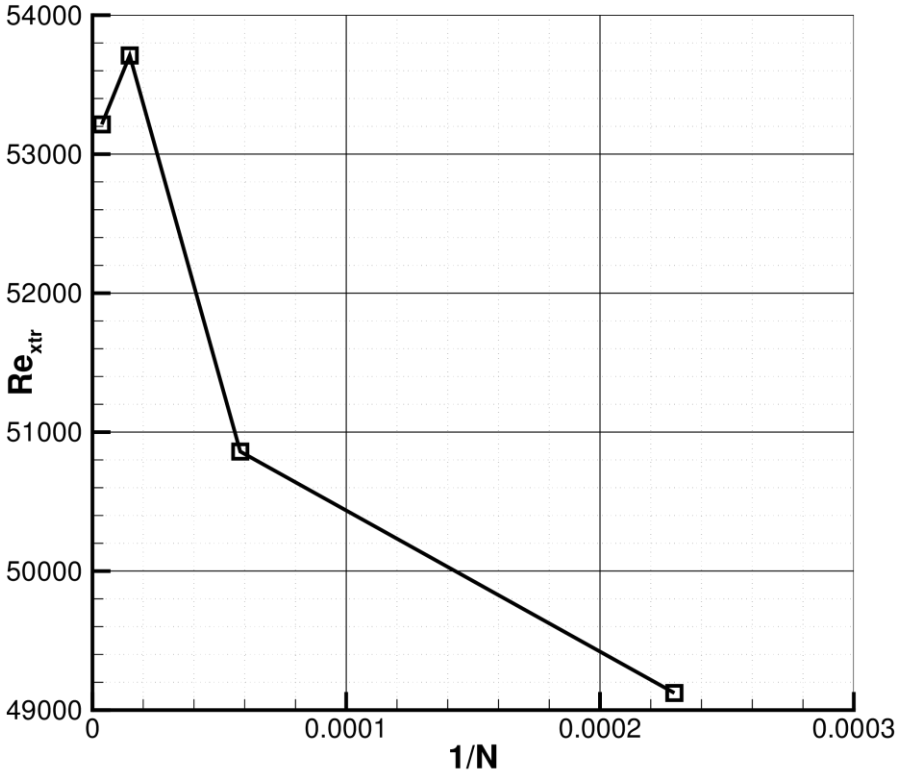




- Improved $x_{tr} \sim \min(c_f)$ as grid refines
- Laminar c_f higher w.r.t experimental data

Case 1B: T3B ZPG

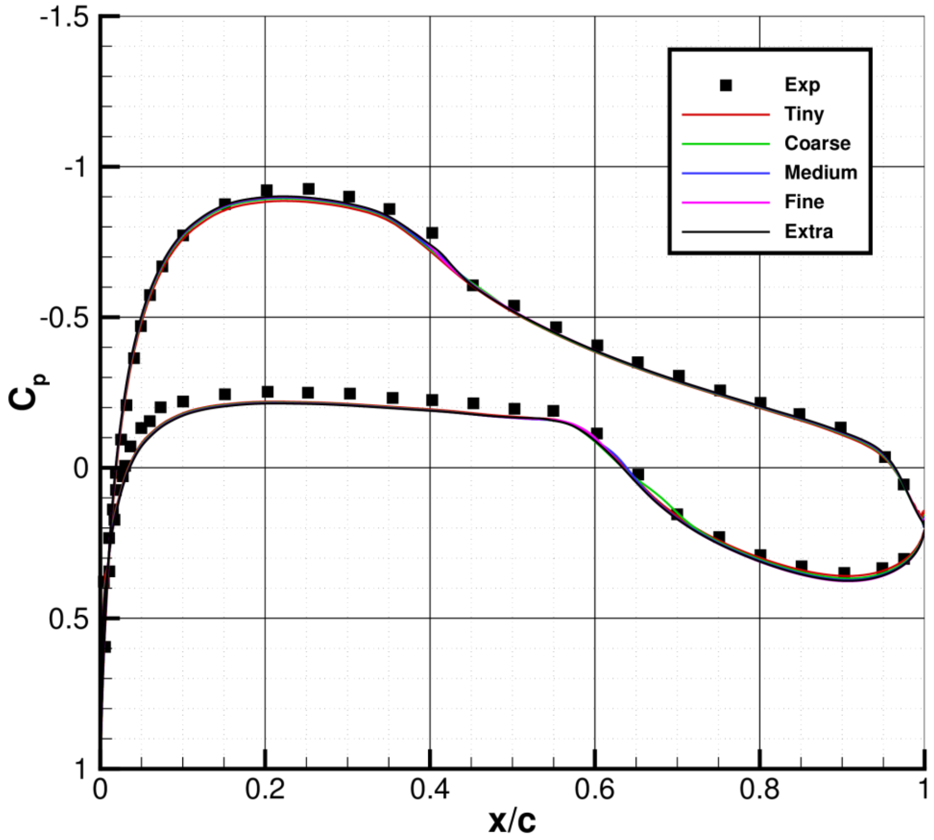


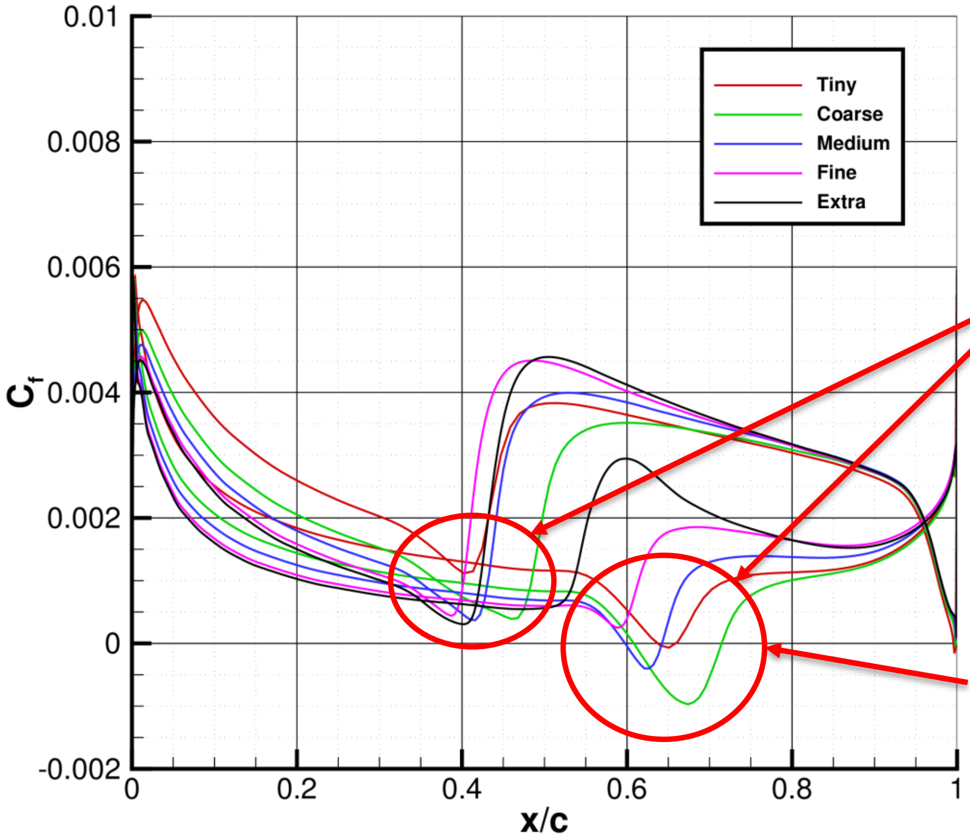


- Improved $x_{tr} \sim \min(c_f)$ as grid refines
- Laminar c_f higher w.r.t experimental data

Case 2A: NLF(1)-0416 Airfoil

$\alpha = 0°$



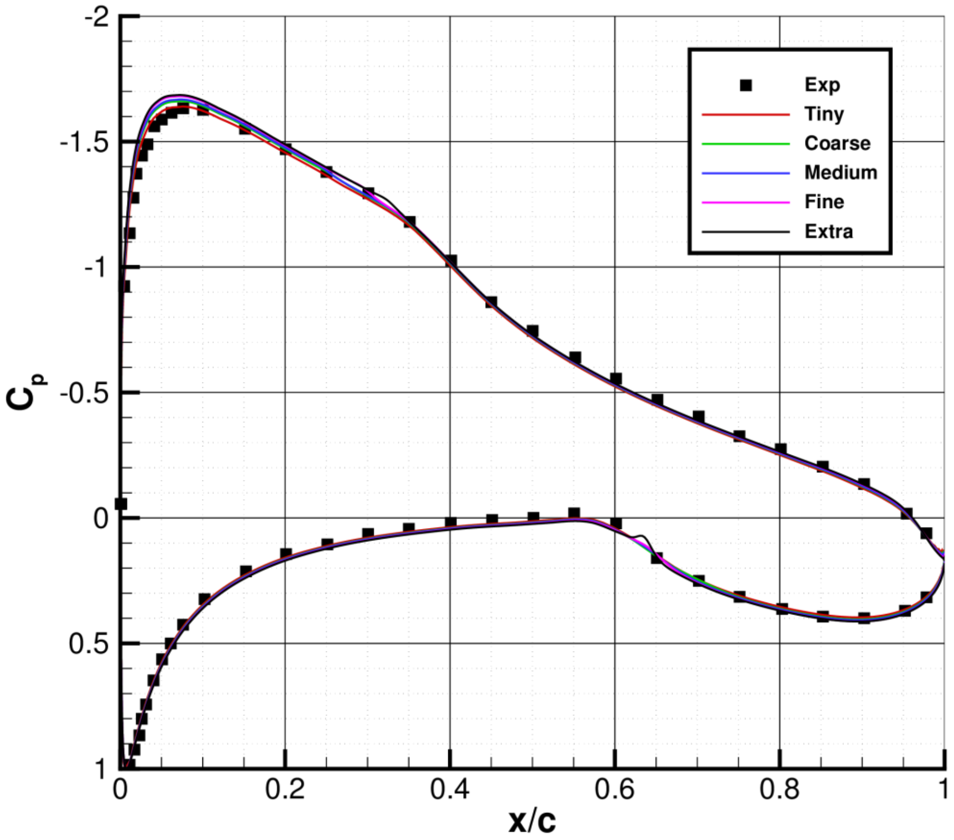


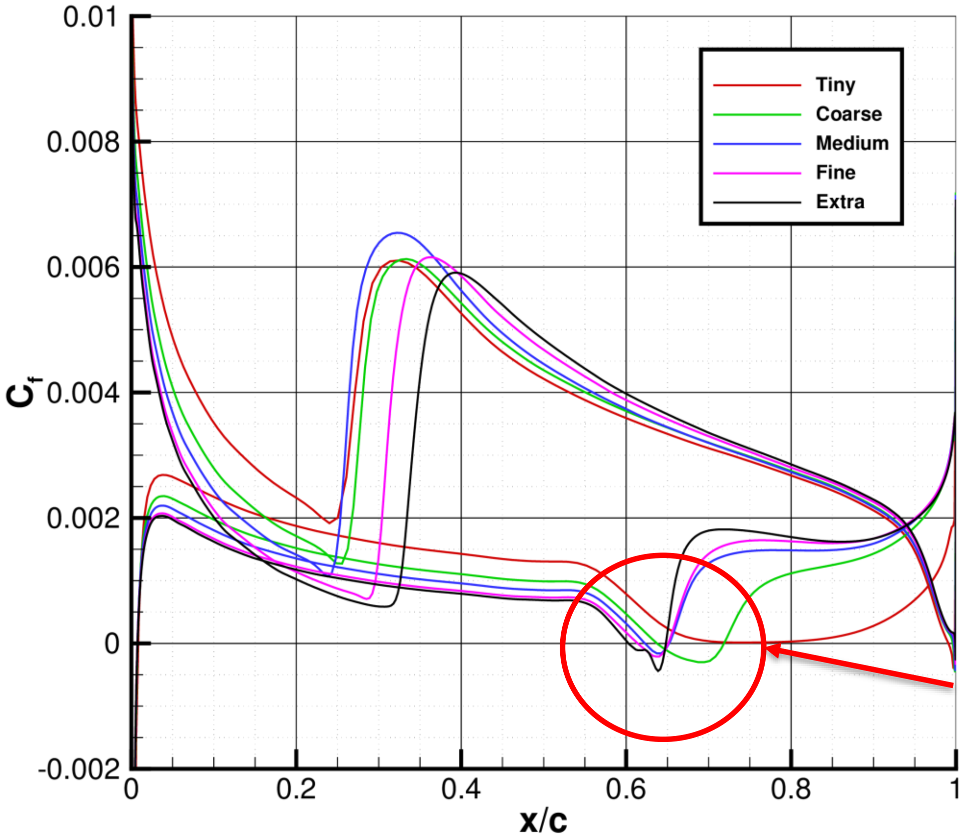
No monotonic convergence on x_{tr}

Separation bubble predicted on T/M/C levels

Case 2A: NLF(1)-0416 Airfoil

$\alpha = 5°$

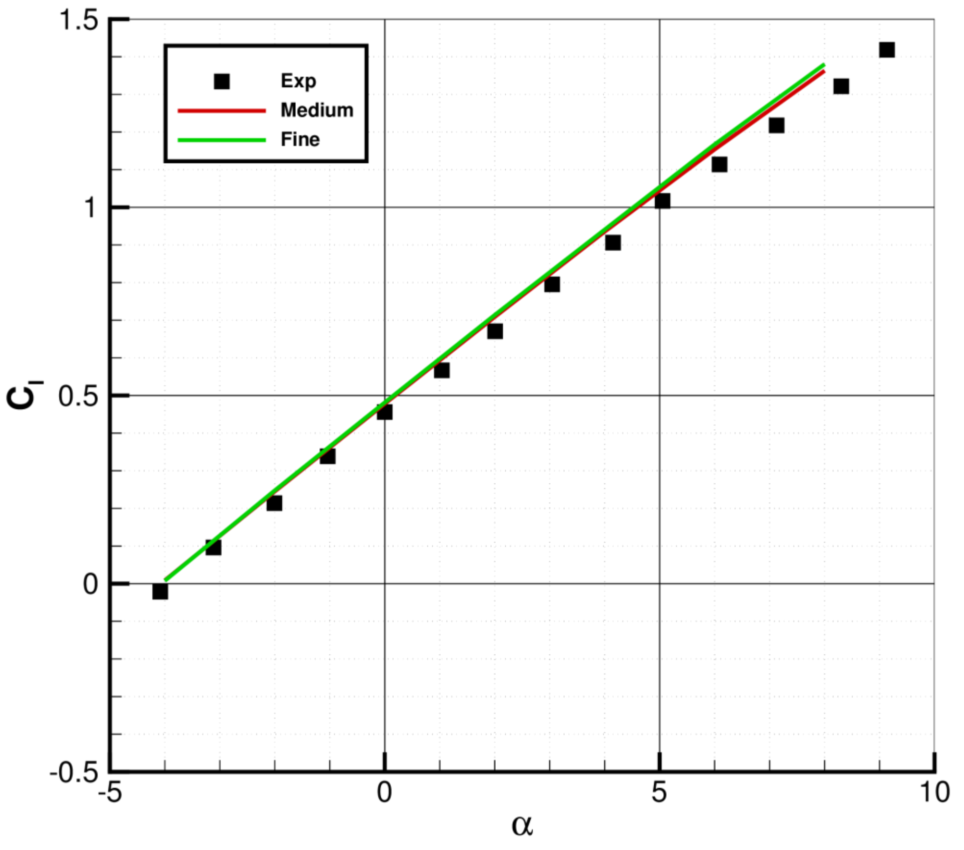


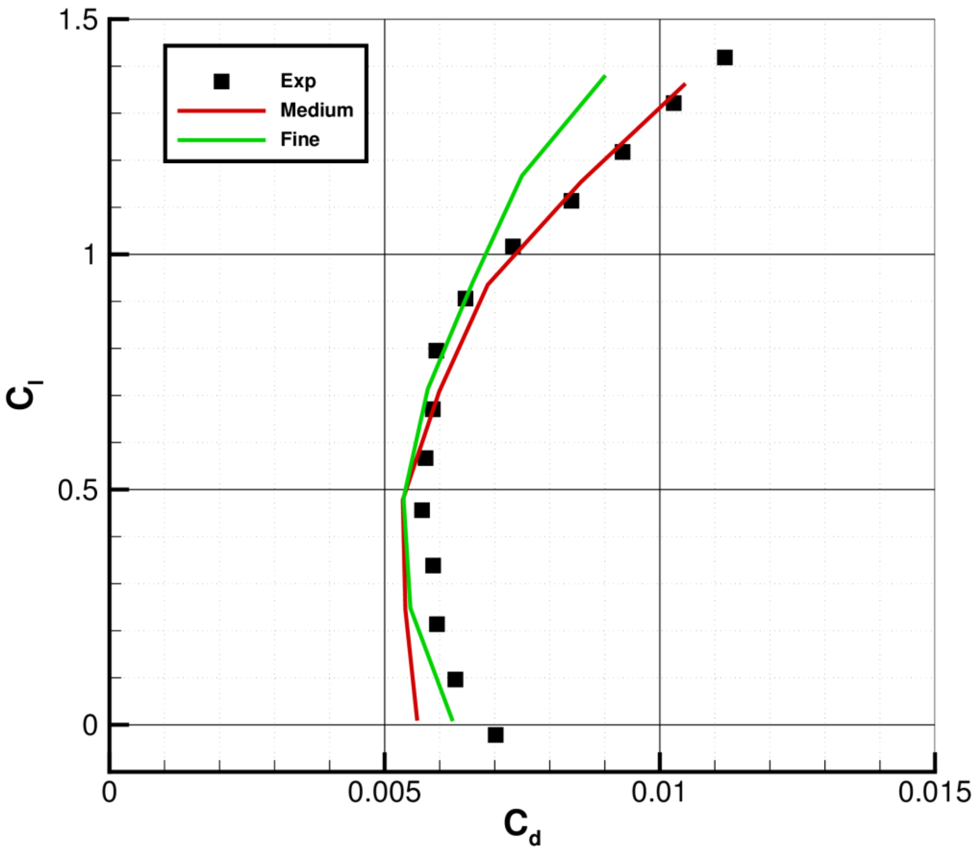


Separation bubble for all levels

“Improved shape”

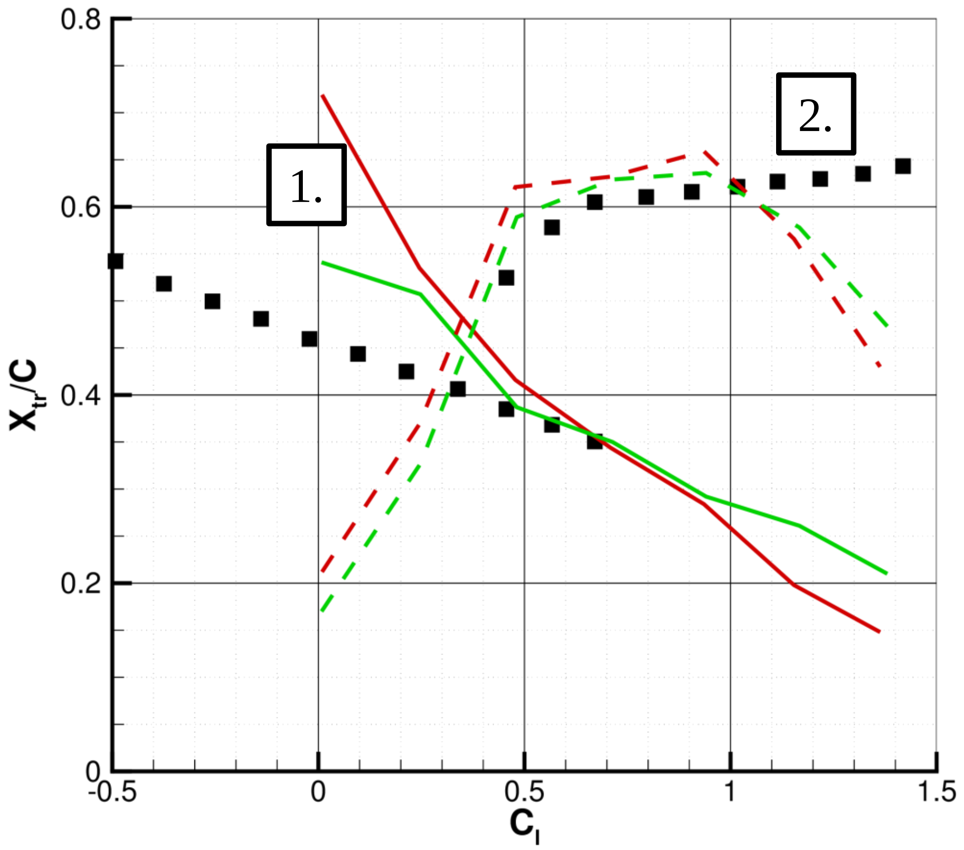
Case 2B/C: NLF(1)-0416 Airfoil

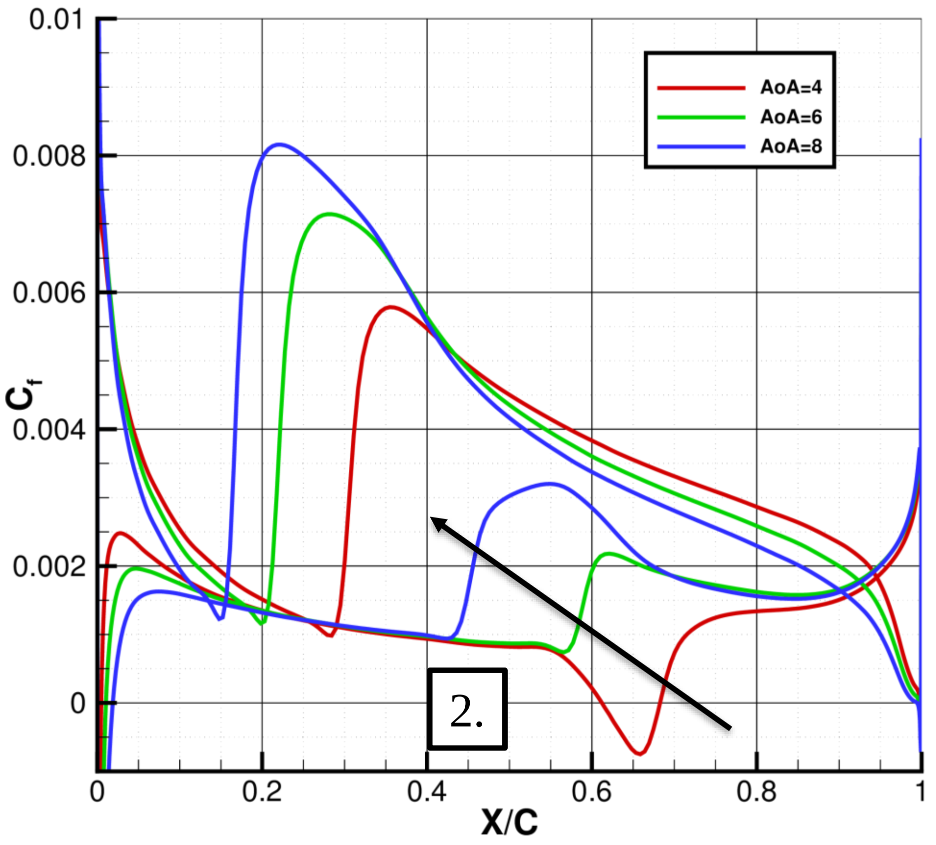




- Good agreement w.r.t experimental data
- Solutions on fine grid underestimate C_d at high α

Case 2B/C: NLF(1)-0416 Airfoil





1. Overestimation on the upper side for low $\alpha < 0°$
2. Misprediction on the lower side for $\alpha \geq 6°$

Conclusions

ZPG Flat Plate

- Improvement in solution refining the grid
- High c_f values w.r.t. experimental data in the laminar region (especially in T3B)

NLF Airfoil

- Grid convergence is not clearly achieved
  - Refining the mesh lowers c_f values in laminar region (expected)
  - No-monotonic shift for the transition point (assumed as $\min(c_f)$).
    - Due to the threshold function?
- Transition point is predicted downstream w.r.t experimental data
  - Misprediction on the lower side for $\alpha \geq 6°$

Italian Aerospace Research Centre

Thanks for your attention!